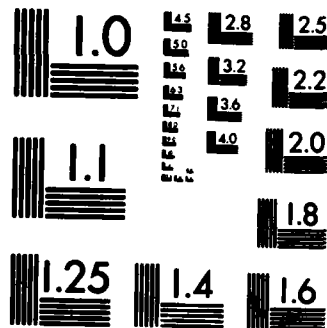END

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FORMATION OF SILICIDE CONTACTS USING CODEPOSITED

REFRACTORY METALS ALLOY FILMS


Final   Technical   Report

for the period : January-December 1983



by

Dr.  Moshe  Eizenberg and Ami Appelbaum

January 1984


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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Contact reactions of a Si substrate and thin films of co-deposited two refractory metals have been studied. Three systems have been chosen Ta-V, Ta-W and Ti-V. As reference also two bilayer structures for each system have been studied (e.g. Ta/W/Si and W/Ta/Si for the Ta-W system). In each system the dependence of the interaction with Si on annealing temperature and on alloy composition is investigated. The interdiffusion and silicide formation have been analyzed by Auger electon spectroscopy and X-Ray diffraction.

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Since both alloy constituents are refractory metals for which silicide formation is controlled by Si outdiffusion, the interaction of these alloys with Si is expected to maintain the uniform components distribution without phase separation. And indeed this is observed for the Ta alloys. On the other hand for the Ti-V alloys, Ti accumulation at the substrate is found. The great affinity of Ti to form a silicide is manifested in the case of the bilayer structure of Ti/V on Si when Ti atoms from the outer region penetrate through the innner V layer and form titanium silicide at the Si interface.

For the alloys studied mutual solubility of both constituents is observed for the as-deposited state and this stabilizes the film and delays silicide formation to higher temperatures. Even the fully reacted films in most cases show mutual solubility of the silicides, e.g. for $Ta_{50}V_{50}$ only $TaSi_2$ reflections without those of $VSi_2$ are observed. Alloying stabilizes also at the earlier stages of reaction metal rich silicides (e.g. $Ta_5Si_3$) that are usually not observed for single refractory metal interaction with Si. No ternary compounds were observed for any of the studies systems.

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1.   Introduction

   Silicides of transition metals are commonly used in the microelec-
tronic industry as ohmic or rectifying contacts on the one hand  and as
gate electrodes and interconnection lines in MOSFET technology on the
other hand.  For the latter use the refractory metal silicides are
utilized due to their low electrical resistivity and their ability to
withstand high temperatures, chemical treatments and thermal oxidation[1].
Recently attention has been drawn to  multi-component metal systems
(alloys and bilayers) on silicon, because of their potential use for
forming shallow contacts on devices whose size is shrinking , to
tailor the Schottky barrier height and to establish a reliable barrier
against Al penetration to the contact area[2]. Extensive work has been
done studying Si  and near noble-refractory metal alloys interactions
that result in phase separation ;[3-8]  the silicide of the near noble
metal (Pd ,Pt  or Ni) is formed adjacent to the substrate while the
refractory  metal ( W, V, or Cr) is found in the outer layer. This
phenomenon has been explained in terms of the differences in the
mechanisms of silicide formation for the two groups of metals.  On the
other hand very limited work has been published on the reaction between
Si  and alloys consisting of two refractory metals [9-11]. In order
to obtain  a better understanding of the metallurgical phenomena
involved in such thin alloy film - silicon reactions, we have
investigated three systems of refractory metals alloys: Ta-W ,Ta-V
and Ti-V.  Ta and Ti have been chosen since their silicides are
currently used in VLSI  technology ; V and W  have been selected as
the alloying agents, the first one reacting with Si at much lower
temperatures than the second one.

The separate behavior of each of the metals on Si is documented[12].
For V, Ta and W only one type of silicide ( the disilicide) is formed
at temperatures above 600, 650 and 700°C respectively, while for Ti- the
disilicide formation is preceded by the appearance of TiSi at ~500°C.
Although this study is focussed on alloy films, we have prepared also
bilayer films of Ta/W , W/Ta , V/Ta, Ta/V, Ti/V and V/Ti on Si. This
was done for two reasons: 1) as reference to observe the behavior of each
metal on Si under our deposition and annealing conditions (recalling that
refractory metal films are very sensitive to impurities such as O of C).
2) to study the interdiffusion between the two metals of an alloy film.

## 2.  Experimental Procedures

n-type Si  wafers with resistivity of $1-10\Omega.cm$  and  $<100>$ orientation were etched in buffered HF, rinsed in DI  water and dried before being loaded into an evaporation chamber operating at $10^{-8}$ Torr.  The metal films were deposited using electron beam evaporation .  The bilayer structures were produced by sequential deposition, whereas for the alloy films codeposition was utilized. The alloy films of $Ta_xW_{100-x}$ ,  $Ta_xV_{100-x}$  and  $Ti_xV_{100-x}$  were prepared in three nominal compositions : $x = 20, 50$ and $80$.  The thickness of the films was 1000-2000 $\overset{o}{A}$.  Annealings (unless other specified of 30 minutes duration) were performed in an evacuated quartz-tube furnace maintained in a vacuum  lower than $3 \times 10^{-6}$ torr.

Two complementary techniques were used to analyze the films in the as-deposited state and following the heat treatments.  Component distrihution was determined by Auger electron spectroscopy (AES) in a  PHI  590A system using a primary beam of 3-4 KeV, $1-2\mu A$ electrons and combined with 4 KeV $Ar^+$ ion etching for depth profiling. Phase identification was carried out by X-Ray diffraction in a standard Phillips powder diffractometer equipped with a stepping motor,controlled and monitored by a 4051 Tektronix minicomputer; detection periods of 20 sec and $0.1^o$  steps (in $2\theta$) were utilized.

## 3. Results

### 3.1 Ta-W

#### 3.1.1 Bilayer Stuctures

The AES depth profile of Ta/W/Si in the as-deposited state is exhibited in Figure 1. The vertical ordinate denotes the Auger peak-to-peak height which is assumed to be proportional to the atomic concentration of each element, whereas the abscissa expresses the sputtering time which corresponds to the film thickness.

Heat treatment up to $750^{\circ}C(30 \text{ min})$ did not show any change in the profile, i.e. tungsten did not react with the substrate and no interdiffusion took place between tungsten and tantalum.

Following an $850^{\circ}C$ anneal the solid state reaction with Si has been observed, as is exhibited in Figure 2. One can note Si penetration through all the W layer and most of the Ta layer; only at the outermost region the reaction is hindered by carbon that probably has diffused inwards from the annealing atmosphere. The X-Ray diffractogram of this specimen is presented in Figure 3. All the peaks match very well the reflections of $TaSi_2$[13] and $WSi_2$ [14]. Thus, we confirm earlier reports[12] that W and Ta directly form on a Si substrate their end product-the disilicide. The formation temperature of $WSi_2$ is $800\text{-}850^{\circ}C$ (for a 30 min annealing period) and $TaSi_2$ is not observed at lower temperatures since the Si atoms must first react with the W layer before encountering the Ta layer.

In the case of the other bilayer, that of W/Ta/Si, $TaSi_2$ was formed as expected following the $750^{\circ}C$ heat treatment. At this temperature the W layer remains intact and it transforms to $WSi_2$ only after annealing at $850^{\circ}C$, which is similar to the above mentioned behaviour for the Ta/W/Si structure.

### 3.1.2  Alloy Films

Three alloys of $Ta_xW_{100-x}$ (x=20,50 and 80) have been investigated. The distribution uniformity of the components in the as-deposited films is observed in the AES depth profiles. The X-Ray diffraction patterns reveal BCC structures with lattice parameters increased with x , as is exhibited in Fig.4 for the (110) reflection.  (It is noted that both metals have a BCC structure).

The initiation of the reaction of $Ta_{80}W_{20}$ with Si is observed after the 750°C anneal and it is completed following the 850°C-30 min heat treatment . The AES profile of this sample is depicted in Figure 5.  One can observe that along most of the profile,(i.e. for sputtering times longer than 22 min) both W and Ta react uniformly with Si without significant accumulation of one of the components. In the outer region there is some carbon accumulation followed by an increase in the Ta signal and a decrease in that for Si. In this region also   ,as with the situation indicated by Figure 2, silicide formation is retarded by the presence of carbon.

The X-Ray diffractogram of the $Ta_{80}W_{20}$ sample following the 850°C anneal is exhibited in Figure 6.  Most of the peaks match very well the reflections of $TaSi_2$[13] and coincide with the corresponding peaks in the annealed bilayer structures(see Figure 3). However, there are five new peaks that do not appear in Figure 3 and which do not match the reflections obtained for $WSi_2$ and $TaSi_2$, but they match perfectly the strong reflections of $Ta_5Si_3$[15].The latter is a phase that is usually not observed for reactions between a thin film of Ta and a Si substrate.  Thus

we detect $TaSi_2$ and $Ta_5Si_3$ without any indication for the presence of $WSi_2$. The higher temperature processing ($950^{\circ}C$) maintains a similar depth profile, but the $Ta_5Si_3$ peaks disappear.

The AES analysis of the $Ta_{50}W_{50}/Si$ sample annealed at $750^{\circ}C$ reveals that no reaction has yet occured, although for pure Ta or for the Ta- rich alloy silicidation is taking place at this temperature. Interaction with the substrate is observed following an anneal at $850^{\circ}C$ ; both metals react uniformly with Si without accumulation of one of the components. X-Ray analysis of this sample exhibits only reflections of $TaSi_2$, without a sign to reflections of W or its silicide. The higher temperature processing of $950^{\circ}C$ maintains a uniform in-depth distribution of the elements, but now in the X-Ray pattern $WSi_2$ reflections are added to those of $TaSi_2$.

For the W-rich alloy composed of $Ta_{20}W_{80}$ no contact reaction with Si is observed even after 2hrs.annealing at $850^{\circ}C$. Impurities ,either in the film or primarily at the Si substrate interface, that could hinder the expected reaction , could not be detected ( to the limit of the AES technique). The interaction with Si is observed following annealing at $950^{\circ}C$ for 30 min. The AES analysis reveals a fully reacted layer( Si reaches the surface) with a uniform in-depth distribution of the elements. By X-Ray diffraction the presence of the expected $WSi_2$ and the metal rich $W_5Si_3$[16] is identified.

## 3.2 Ta-V

### 3.2.1 Bilayer Structures

The reaction of the bilayer structures Ta/V and V/Ta with Si was examined using Auger analysis technique. For Ta/V on Si, the reaction of V with Si occurs at $650^{\circ}C$, while the reaction of Ta with Si (for both

structures) is observed at $750^{o}C$. The phases are $VSi_2$ and $TaSi_2$, respectively. However, intermixing of metals does not occur in heat treatments up to $850^{o}C$.

### 3.2.2  Alloy Films

Three alloys of $Ta_xV_{100-x}$ (x=20,50 and 80)have been investigated. The distribution uniformity of the components in the as deposited  films was observed in the Auger depth profiles. Similarly to the case of Ta-W  the X-Ray diffraction patterns reveal BCC structures with lattice parameters increased with x(again it is noted that  both metals have a BCC structure).

For the $Ta_{80}V_{20}$ alloy no reaction is observed after a $650^{o}C$ annealing , the temperature where $VSi_2$ is formed for Ta/V/Si. Partial reaction is observed following an annealing at $750^{o}C$, as can be observed in Fig. 7 . The reaction is completed after a $850^{o}C$ heat treatment. No preferred accumulation of one of the elements is observed in the AES profiles. The phases identified by X-Ray  diffraction are $TaSi_2$[13] for the $750^{o}C$  anneal and $TaSi_2$  plus Hexagonal $Ta_5Si_3$[15]  for the $850^{o}C$ anneal. The Ta-rich silicide, that is not detected in annealed Ta films on Si , is the same phase reported above for the $Ta_xW_{100-x}$ alloys.

$Ta_{50}V_{50}$ starts reacting with Si at $750^{o}C$. X-Ray  diffraction yields a set of reflections that are attributed to two $Ta_5Si_3$ phases (hexagonal [15] and tetragonal [17])and to $TaSi_2$  structure with a slightly  distorted lattice parameter (this will be explained in sect. 4.3  by the formation of a solid solution of $TaSi_2$ and $VSi_2$). The reaction is completed following a heat treatment at $850^{o}C$. The metal rich silicide  disappears  and  the reflections of $TaSi_2$ are shifted even more. The vanadium rich alloy $Ta_{20}V_{80}$ reacts with Si

forming $VSi_2$ already after a heat treatment at $650^{\circ}C$ for 30 min. For this alloy as for all other $Ta_xV_{100-x}$ films no accumulation of one of the elements is observed by the AES depth profiling.

## 3.3 Ti-V

### 3.3.1 Bilayer Structures

V/Ti and Ti/V bilayers on Si have been investigated. The deposited products are two separate layers of V and ρ-Ti ( a BCC phase obtained in bulk material only at high temperatures [18]). A very small amount of Ti in the V film is found already at the as-deposited state, probably indicating some accumulation at grain boundaries. For both bilayers Ti diffuses through the V layer during the anneal at temperatures equal to or higher than $650^{\circ}C$. In both cases Ti is oxidized on the surface and forms a silicide at the Si-metal interface, showing a rapid transport of Ti through the V film. This is exhibited for Ti/V/Si annealed at $750^{\circ}C$ in Fig. 8, where we see the titanium oxide and titanium silicide accumulations for sputtering times 0-8 and 50-65 min., respectively . The identified phases are $VSi_2$ and TiSi.[19] The $TiSi_2$[20] which is expected to form at this temperature, is not detected. For the opposite structure of V/Ti on Si the penetration of Ti through the V and oxidation on the surface is much smaller (Fig. 9); the reaction with Si starts at ~ $550^{\circ}C$ . The $850^{\circ}C$ annealed sample (Fig. 9b) is well behaved- a uniform reaction with V (resulting in $VSi_2$ formation ) and with Ti (resulting in $TiSi_2$ + some TiSi) is observed. On the other hand for the $750^{\circ}C$ annealing (9a) the V region is non uniform - a dip in the Si signal accompanied by a pile-up of V and C is observed for sputtering times of 4-10 min. The phases identified by X-Ray are $V_5Si_3$[21] and TiSi plus $TiSi_2$.

A metal rich phase for Ti is also identified - for the $650^{\circ}$C heat treatment $Ti_5Si_3$[22] plus TiSi are formed.

### 3.3.2  Alloy Films

Three alloys of $Ti_xV_{100-x}$ were investigated : $x$ = 20,50 and 80. According to the Auger depth profiles the elements distribution in the as-deposited films is uniform.  The X-Ray diffraction patterns of the alloys reveal BCC structures with lattice parameters that have intermediate values between those of $\beta$-Ti and V.

The reaction with Si is noted after 30min anneal at $600^{\circ}$C for the $Ti_{50}V_{50}$ alloy and at $550^{\circ}$C for the other two compositions. The alloys with $x$ = 80 and 50 reveal non uniform redistribution following the interaction with Si; enrichment with titanium silicide at the substrate interface is observed, as shown in Fig.10 .  The X-Ray analysis of the Ti- rich $Ti_{80}V_{20}$ sample following the 700 and $750^{\circ}$C annealings ( see Fig. 11) shows three titanium silicides ( $Ti_5Si_3$, TiSi and $TiSi_2$) and the vanadium discilicide ($VSi_2$).  Following the $850^{\circ}$C heat treatment, the metal rich silicide disappears.  For the other two compositions ($Ti_{50}V_{50}$ and $Ti_{20}V_{80}$) only $VSi_2$ is revealed by the X-Ray analysis.

## 4. Discussion

The discussion of the experimental results will be focussed on four aspects : 1) The structure of the as-deposited films, 2) The reaction temperatures , 3) The reaction products , and 4) The components distribution as a result of the reaction.

### 4.1. Structure of the As-Deposited Films

The X-Ray diffractograms (both the patterns and the peak locations which vary with the amount of alloying ) for all alloys in the as-deposited state clearly show mutual solubility of the components. And indeed this is expected for the Ta-W system since the equilibrium phase diagram is of complete solubility[23]. From the phase diagram of Ta-V[24] at room temperature the Ta-rich composition of $Ta_{80}V_{20}$ is expected to be in a solid solution phase, while for the two other compositions studied ($Ta_{50}V_{50}$, $Ta_{20}V_{80}$) a mixture of this phase with a $\sigma$ phase is expected. However, for high temperatures (>1322°C) complete solubility should be obtained for all compositions. For the Ti-V system the phase diagram[23] at room temperature predicts complete solubility for the $Ti_{50}V_{50}$ and $Ti_{20}V_{80}$ alloys and a mixture with an $\alpha$ - Ti phase for the Ti-rich composition. Here again at high temperatures (>600°C) complete solubility is expected also for the latter alloy. The experimental observations for all alloys in the as-deposited state are the detection of a single phase of a solid solution, namely, the high temperature rather that the room temperature structure is- obtained for Ta-V and Ti-V . A similar result is observed for the Ti film in the bilayer sample where the high temperature structure of BCC β-Ti is obtained rather than the hexagonal α-Ti . These results are not surprising

(we observed it also for the Ni-Cr system [8]) since it is well established that the deposition process is not an equilibrium one and it can freeze higher temperature structures[25].

## 4.2    Reaction Temperatures

The temperatures (for 30 min anneals) where interaction with Si is observed by AES for the various compositions studied are summarized in Table I . (The alloys are organized so that the parameter x denotes the atomic concentration of the metal with the higher formation temperature). The formation temperatures for the single metals, as derived from the data for the bilayer structures, confirm earlier reports[12]. The more interesting case is that of the alloys, where we observe for some compositions a delay in the reaction temperature compared to the pure metal with x =0. A delay (or reduction in reaction rate) can be attributed either to impurities or to effects of the alloying.  The slowing down of silicide formation by impurities such as  O  is not new and has been reported[26].  And indeed in a few cases in our study we have observed that presence of C (probably from unefficient trapping of oil from the diffusion pump used in the early stages of the research), prevented silicide formation probably by arresting the metal atoms in the form of carbide. ( Indications of presence of carbides were found in the line shape of the Auger transition of carbon for those samples). But for the samples summarized in Table I with the delay in reaction temperature, no impurities that could be blamed for this behavior were detected either in the film or at the substrate interface.  We interpret the delay in silicide formation as resulting from the alloying recalling that for all alloys studied our X-Ray results  prove that the as-deposited films are in the form of a solid solution.

The logical approach to analyze the alloying effects is first to see what is the expected behavior according to thermodynamics, namely to consider the driving force leading to the dissociation of the solid solution. The analysis presented in ref. 2, 4 can be implemented also in our case. In Fig.12 an idealized sketch of free energy vs.composition diagram of a binary system A-B is presented. Assuming that B is the metal with the lower silicide formation temperature (V in Ta-V, Ti in Ti-V,and Ta in Ta-W), then the depletion of B from the A-B solution in order to react with Si will increase or decrease the free energy of the alloy according to the alloy composition in the directions of the arrows in Fig.12. One can see that an increase in $\Delta G$ for A rich and a decrease for B-rich compositions is expected, thus the first case in less thermodynamically favored. Namely, we can explain on thermodynamical background the retardation of silicide formation of the metal with lower formation temperature in alloys where this element is the minority component. This may explain the increase in the formation temperature for $X \geqslant 50$ of the $W_x Ta_{100-x}$ and $Ta_x V_{100-x}$ alloys (Table I ) and possibly also the case of $Ti_{50}V_{50}$. Such an argumentation was used in earlier studies to explain the increase in silicide formation temperatures of near noble metals for near-noble refractory metals alloys (Pd-V[4], Pd-W[2,7], Ni-Cr[8]), In another case, Ir-V, silicide formation was slowed down by intermetallic components consisting of both metals[27,28]. However, the role of thermodynamics may not be so important in thin film interactions under conditions far from equilibrium,and changes in reaction rate may be related also to other effects such as mechanical stresses or changes in diffusion mechanism due to modifications in the composition and structure of the matrix.

## 4.3 Reaction Products

The reaction products for the bilayer structures are the expected silicides, confirming earlier reports for the separate interaction of each of the elements with $Si^{[12]}$. However, for the alloys there are some deviations from the simple expectation to observe each of the elements to react separately with Si. Thus for example for reacted $Ti_{50}V_{50}$ we observe only $VSi_2$ reflections without those of titanium silicide. Such an observation should first be compared With the predictions of a ternary phase diagram of the Ti-V-Si system which is unavailable. However, Nowotny et al., [29] studied the pseudo-binary compound $(TiSi_2)_x-(VSi_2)_{100-x}$ for various x at high temperatures (>1350°C) and found that the hexagonal lattice of $VSi_2$ can dissolve up to 85 molar percents of $TiSi_2$. These high temperature bulk results may explain the missing reflections of Ti-silicides observed at 750-850°C. A similar result is obtained for $Ta_{50}V_{50}$ where following 850°C annealing no reflections of $VSi_2$ are found and those of $TaSi_2$ are shifted in their positions. Again it may be explained by dissolution of $VSi_2$ in the $TaSi_2$ lattice.

Another effect of the alloying on the reaction products is the appearance of metal rich silicides $M_5Si_3$ (Such as $Ta_5Si_3$ or $Ti_5Si_3$). Such compounds are usually not obtained for the reaction of thin films of a refractory metal with Si, but are stabilized by the presence of $C^{[18]}$ (e.g. for the interaction of $Ti_xC$ with $Si^{[30]}$) or when the Si supply is limited ( e.g. cosputtered Ta or Ti with Si on $SiO_2^{[1]}$). The first case is also noted in this work where $V_5Si_3$ is found for the V/Ti bilayer in the outer region of the vanadium that is loaded with C ( Fig. 9a) . But alloying a refractory metal with another refractory metal apparantly also stabilizes the $M_5Si_3$ phase; it is observed for all three alloy systems reacting with Si when no impurities were detected. Whether this is a kinetic effect or is expected by thermodynamics(we

recall again that ternary phase diagrams are not available) has not been determined within the frames of the present work and deserves further studies. Some support to the kinetic assumption is found by the fact that the metal rich phases are stable only in a small range of temperatures and disappear following higher temperature anneals.

Although we observe alloying to affect the reaction products by stabilizing $M_5Si_3$ phases and by dissolving some silicides in the lattice of others, no ternary compounds have been detected by us. The appearance of a ternary may be expected for Ta-W due to the close atomic sizes of Ta and W and their similar electronic configurations; however to the best of our knowledge such compounds were not detected even in the case of bulk samples. Again the lack of ternary phase diagram does not enable to comment whether they are expected at all. Usually the interaction of thin alloy films with Si does not lead to production of ternary compounds ; they are found only in a few cases. For alloys consisting of two refractory metals, the interaction of Ti-W on Si is reported [10] to yield such a compound.

## 4.4 Components Distribution

For the Ta-V and Ta-W bilayer structures each of the layers reacts separately with Si without interdiffusion between the metals and thus structures of $TaSi_2/VSi_2/Si$ , $VSi_2/TaSi_2/Si$ ,$TaSi_2/WSi_2/Si$ and $WSi_2/TaSi_2/S$ are finally obtained. Since for these metals silicide growth is dominated by Si outdiffusion[12] this result is not surprising . Therefore we are also not surprised to observe a uniform distribution of the components for the reacted Ta alloys ,$Ta_xV_{100-x}$ and $Ta_xW_{100-x}$.

The case of Ti-V differs from the other two systems. For the bilayer structures one observes Ti penetration through the V layer; for Ti/V/Si inwards diffusion to form Ti silicide adjacent to the substrate is observed , and for V/Ti/Si some outwards diffusion to form Ti oxide is noted. The driving force is of course the reduction in free energy by the formation of Ti silicide or oxide, and the mechanism is probably via grain boundary diffusion. We assume this mechanism since already for the as-deposited films we observe presence of some Ti in the V layer, and the occurrence of this phenomenon at such low temperatures ( the substrate was not deliberately heated during deposition and its temperature rise is estimated to be $\sim 60^0$C) rules out any other transport mechanism. It is assumed that this mechanism is dominating also at the range of temperatures of 600-850$^0$C when the solid state reactions take place. It is interesting to note that for bulk diffusion at higher temperatures the diffusion of V in Ti is faster than that of Ti in V[31].

The relatively fast permeation of Ti through the V layer can also explain the Ti accumulation near the substrate observed for the Ti-V alloys. Thus although both metals belong to the same group of refractory metals where silicide growth is dominated by Si outdiffusion, partial spacial phase separation is found, similarly to the case of the alloys consisting of a near noble and a refractory metal. In the latter case the phase separation was attributed to different diffusion mechanisms for silicide growth of both types of metals. Our results seem to indicate that some metal diffusion cannot be rulled out for Ti silicide growth, and in fact this can also explain its low formation temperature relative to other refractory metals. We recall that some

accumulation of $CrSi_2$ adjacent to the substrate for another refractory-refractory alloy (Ta-Cr) has also recently been reported[11] and again the formation temperature of $CrSi_2$ is relatively low.

4.    <u>Summary</u>

The three studied systems of two refractory metals on Si share many properties. The as-deposited alloy films are in a single phase structure of a solid solution which delays in many cases the temperature of silicide formation. At the early stages of reaction metal rich compounds($M_5Si_3$) appear, which later are replaced by the expected disilicides. However, for $Ti_xV_{100-x}$ the titanium silicide is dissolved in the $VSi_2$ lattice, whereas for $Ta_xV_{100-x}$ the $VSi_2$ is dissolved in the $TaSi_2$ lattice ; for the $Ta_xW_{100-x}$ system there are conditions when both silicides are simultaneously detected. For all systems no ternary compounds are found. For the systems containing Ta the metals maintain their spacial distribution upon reaction with Si, whereas for Ti-V, both for the alloys and the bilayer structures, upon silicide formation Ti accumulation adjacent to the substrate is observed.

The results summarized so far were obtained during an intensive study which was unexpectedly limited by funding only to one year, and therefore could not encompass all aspects. Open interesting topics from the pratical point of view for these alloys are the electrical properties of the alloy-Si interface, and their interaction with a top metallization of Al. And of course more metallurgical effort can yield results about reaction mechanisms and rates.

## Acknowledgements

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Table I

| x | $W_x Ta_{100-x}$ | $Ta_x V_{100-x}$ | $V_x Ti_{100-x}$ |
|---|---|---|---|
| 0 | $750^{\circ}C$ | $650^{\circ}C$ | $550^{\circ}C$ |
| 20 | $750^{\circ}C$ | $650^{\circ}C$ | $550^{\circ}C$ |
| 50 | $850^{\circ}C$ | $750^{\circ}C$ | $600^{\circ}C$ |
| 80 | $950^{\circ}C$ | $750^{\circ}C$ | $550^{\circ}C$ |
| 100 | $850^{\circ}C$ | $750^{\circ}C$ | $650^{\circ}C$ |

Formation temperatures (for 30 min anneals) of silicides for films studied.

x denotes atomic concentration of the metal with higher formation temperature.

## Figures

Figure 1


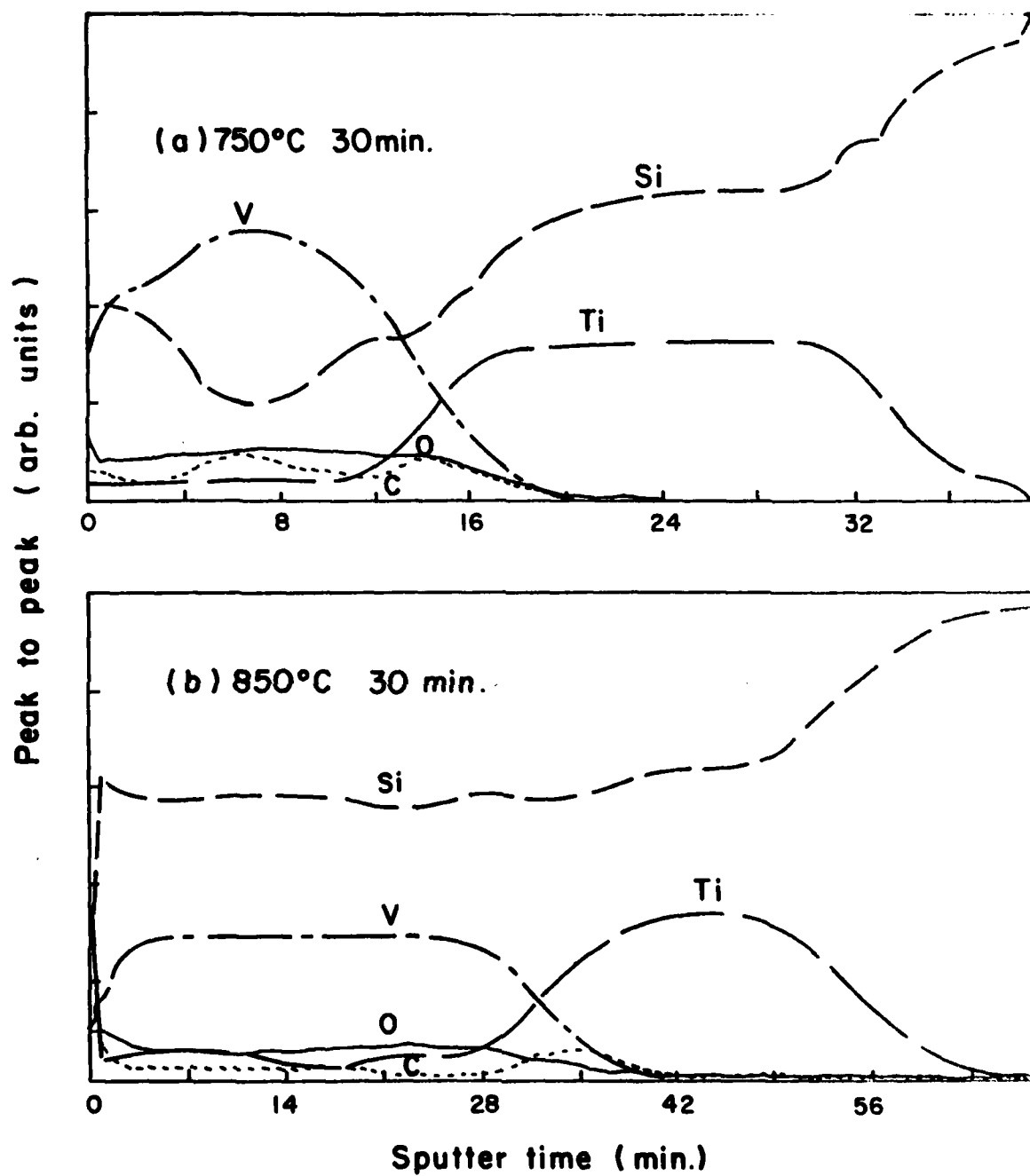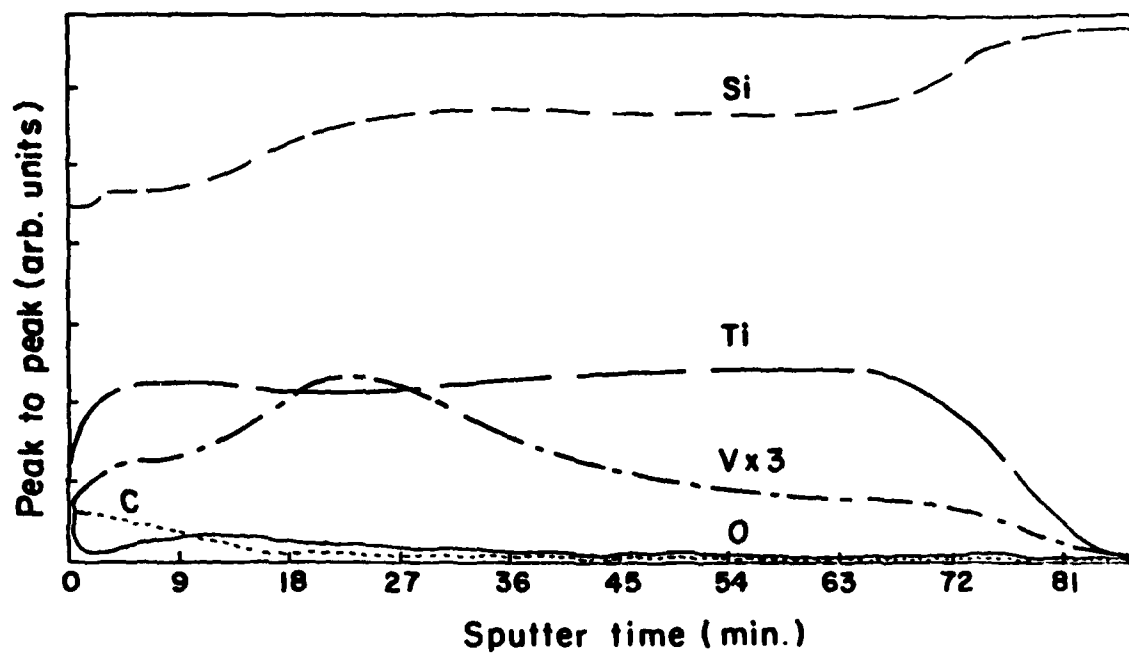
Figure 2



Figure 3

Figure 4
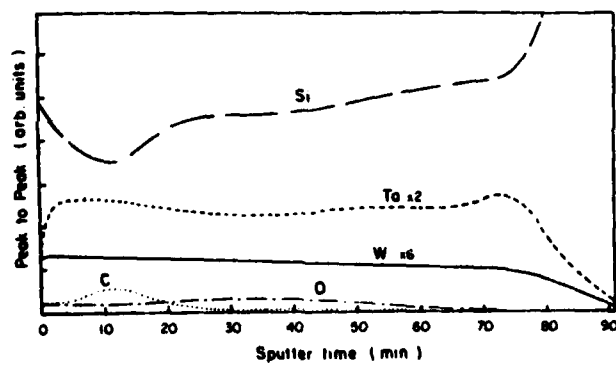


Figure 5
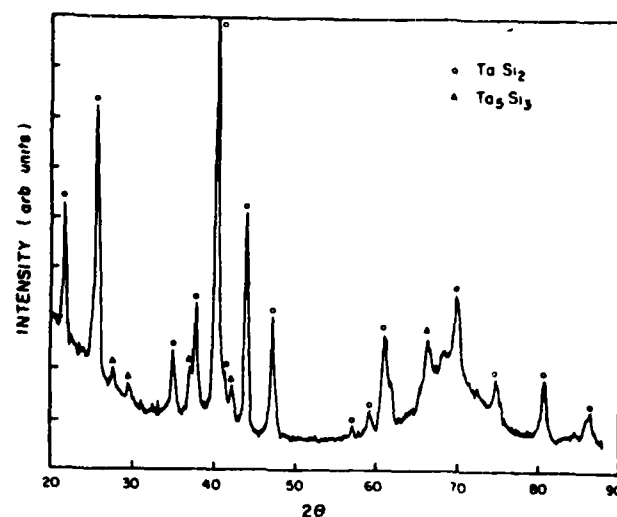
Figure 6
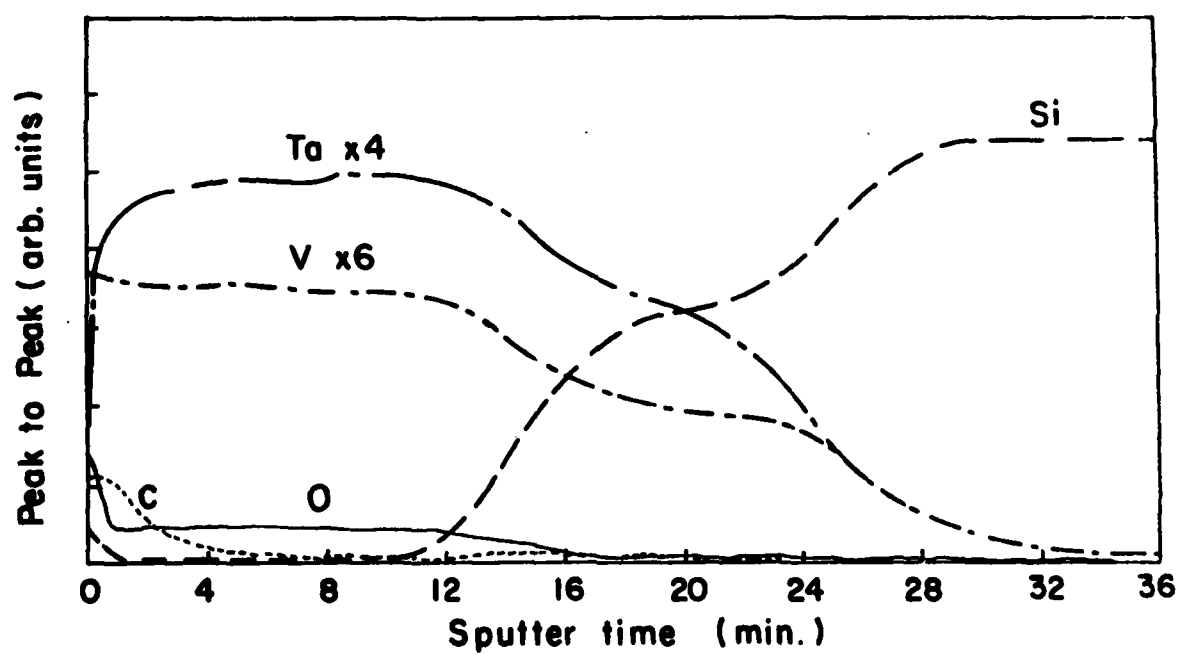


Figure 7
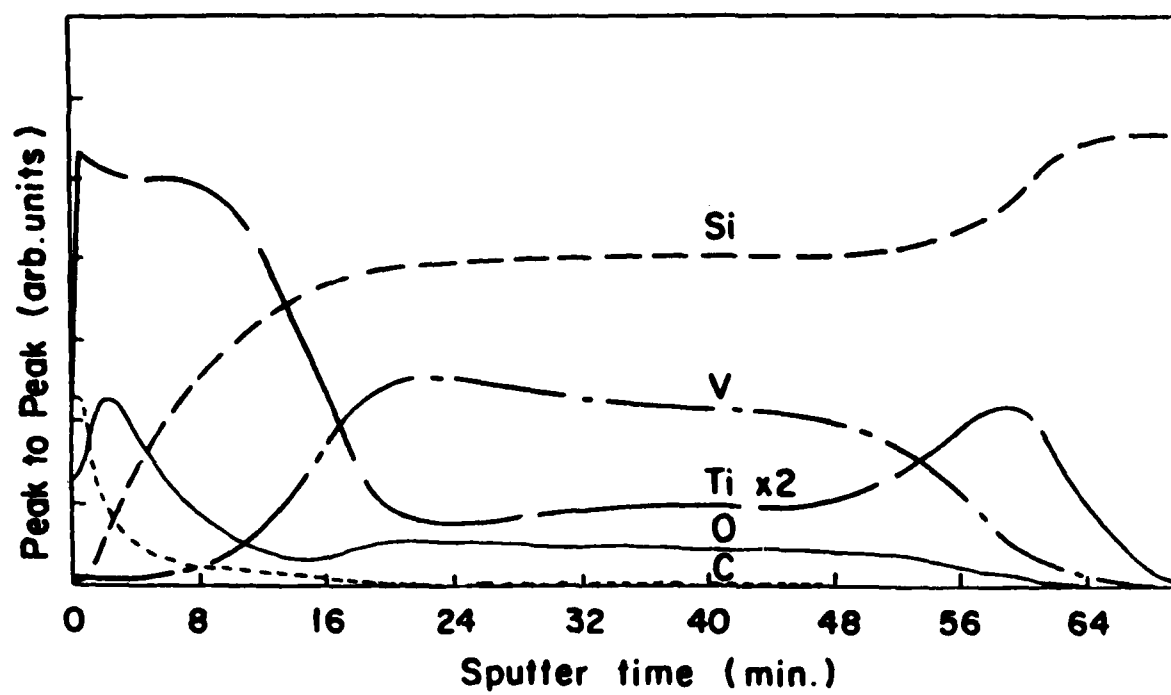
Figure 8

Figure 9

Figure 10



Figure 11

Figure 12

# END